RAW MATERIALS

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INTEGRATED STUDY OF IRON ORE CONCENTRATION PRODUCTS FOR PRODUCING SILICATE MATERIALS

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The results of an integrated study of waste generated in moist and dry concentration of ferrous quartzite are presented, and their melting temperature, phase composition, and behavior in heating are identified. The possibility of using this waste as the basis or an additive in the production of wall ceramics, household articles, glaze coatings, and glass ceramic materials is established.

The need to use rationally available fuel and energy resources calls for the development and upgrade of new silicate compositions using nontraditional raw materials. The latter include the waste generated in the concentration of ferrous quartzites from the Okolovskoe deposit (Republic of Belarus). The geological-mineralogical characteristics of this material differ from known rocks, which is due to the peculiarities of its formation and bedding, typical of the magnetite-quartzite crystalline foundation of Belarus [1].

The Okolovskoe iron ore deposit is located in the Minsk Region. It occurs under a sheath of sedimentary rocks, extends for 180 km in the north-east direction, is 10 – 30 km wide, and is represented by various gneiss, amphibolites, ferrous quartzites, and other rocks. The productive (iron ore) rocks have thickness from 30 to 120 m and constitute about 28 – 35% of the total rock volume. In mining this deposit a huge (hundreds of thousands of tons) volume of ore-free rocks will be dumped on dumping grounds after the concentration and magnetic separation of ferrous ores. It is known that the profitability of any mineral deposit can be raised by a fuller extraction and integrated use of the maximum possible number of useful components [2].

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The concentration of iron quartzites generates two types of waste: dry and wet magnetic separation tails. The analysis of the chemical composition of this waste (Table 1) suggests that it can be a valuable mineral material for producing silicate material for different purposes. The fractional composition of the waste from dry and moist magnetic separation of iron ores is given in Table 2.

For the purpose of determining the melting point of the initial raw materials, we carried out a multiposition treatment of powders in the temperature interval of 1100 – 1300°C with a step of 50°C and an exposure for 30 min at each position. The visual characteristics of samples after heat treatment indicated that the melting temperature of the samples of dry and moist magnetic separation tails is 1170 – 1230 and 1130 – 1170°C, respectively. The lower melting temperature of the tails of moist concentration of ferrous quartzites is presumably due to the increased content of Fe_2O_3, which is known to have a fluxing effect and pass into the melt.

To estimate the applicability of these material, we carried out an integrated study (differential thermal and x-ray phase

TABLE 1

Tails from magnetic separation	Weight content, %												
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	calcination loss
Dry	55.95 – 61.05	0.19 – 0.24	5.99 – 6.09	2.41 – 3.99	14.72 – 18.22	0.25 – 0.40	6.34 – 7.12	4.28 – 5.12	0.30 – 0.36	0.83 – 1.10	0.69 – 0.86	0.12 – 0.15	1.09 – 1.83
Moist	49.97 – 53.09	0.21 – 0.25	5.83 – 6.75	7.35 – 10.00	15.26 – 18.94	0.21 – 0.34	6.44 – 7.40	4.04 – 4.58	0.40 – 0.50	0.96 – 1.20	0.84 – 0.88	0.12 – 0.13	0.12 – 0.13

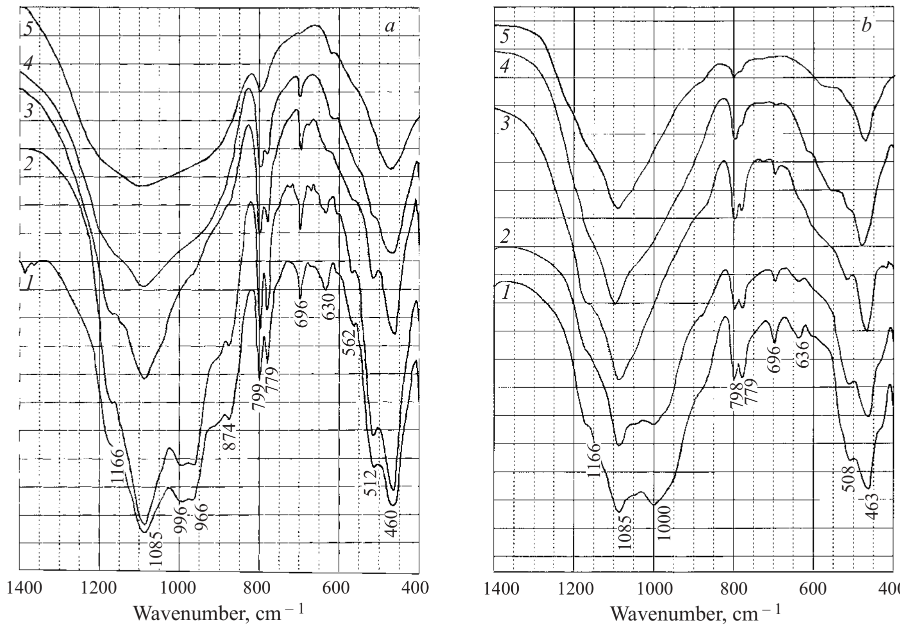

Fig. 1. IR absorption spectra of the waste of ferrous quartzite after dry (*a*) and moist (*b*) concentration: *1*) initial sample; *2*, *3*, *4*, and *5*) heat treatment temperatures 500, 1000, 1250, and 1450°C, respectively.

analysis, infrared spectroscopy) and investigated the behavior of the materials in heating under temperatures of 500, 1000, 1250, and 1450°C.

According to the DTA data, the thermograms of both material samples exhibit intense thermal effects. The first exothermic effect with a maximum at 450 – 455°C is presumably due to the oxidation of an insignificant quantity of Fe^{2+}. The presence of two endothermic effects with minima at 540 – 550 and 720 – 740°C is presumably due to the removal of the main part of the structural and residual constitution water, as well as oxidation of bivalent iron [3].

The x-ray phase analysis indicated that the mineral composition of tails from dry magnetic separation includes quartz, hornblende, chlorite group minerals, hematite, and magnetite. Furthermore, anorthite, calcite, and biotite are present in insignificant quantities. The mineral composition of the tails of moist magnetic separation is represented by the same crystalline phases but the intensity of the diffraction maxima of anorthite and quartz are higher than in dry separation.

TABLE 2

Class, mm	Quantity of fractions, %, in magnetic separation tails	
	dry	moist
> 1.0	2.2	8.7
1.0 – 0.63	4.5	
0.63 – 0.315	12.8	
0.315 – 0.16	16.1	
0.16 – 0.1	12.8	
0.1 – 0.071	9.0	
0.071 – 0.045	22.1	22.6
< 0.045	20.5	68.7

It should be noted that the phase composition of this material is complicated, and therefore, it is difficult to identify particular crystalline phases. Thus, hornblende is represented by a group of minerals (cummingtonite, actinolite, tremolite) and their solid solutions with close or even identical parameters of the crystal lattice.

The diversity of the chemical composition of some representatives of the chlorite family is due not only to the wide isomorphism of its main constituent elements: $Mg^{2+} \to Fe^{2+} \to Mn^{2+}$, $Al^{3+} \to Fe^{3+} \to Cr^{3+}$, but also to the simultaneous replacement of Si^{4+} and Mg^{2+} by $2Al^{3+}$ and $3Mg^{2+}$ by $2Al^{3+}$. Due to these substitutions the chlorite group has a multitude of isomorphic varieties known under different names that cause certain difficulties in identifying crystalline phases. The general formula of minerals of the chlorite groups is $X_{4-6}Y_4O_{10}(OH)_8$ (X is a cation in six coordination with respect to oxygen; Y is Al^{3+}, Si^{4+} in four coordination). In the present work the reference standards in deciphering diffraction patterns were the diffraction maxima corresponding to the parameters of the crystal lattice of chamotte $(Fe^{2+}, Mg, Fe^{3+})_5Al(Si_3Al)O_{10} \cdot (OH, O)_8$.

For complete information on the structural and phase transformations occurring in heating the waste of ferrous quartzites after dry and moist concentration, the IR spectroscopic analysis of initial material samples heat-treated at 500, 1000, and 1250°C and of melts obtained at 1450°C and representing well-melted black glasses (Fig. 1) was performed.

The analysis of the IR absorption spectra indicates that they are similar in both samples. The spectra of the initial samples exhibit two wide absorption bands in the range of 830 – 1200 and 400 – 600 cm^{-1}, which can be attributed to the valence and deformation vibrations of Si – O – Si bonds in the chain-like and ribbon structures, respectively.

The published data on the spectra of minerals of the hornblende, tremolite, and actinolite types indicate the presence of a group of intense and partly overlapping bands in the range of 900 – 1100 cm^{-1} (in our case 966, 996, and 1085 cm^{-1}) and a group of less intense bands in the range of 780 – 640 cm^{-1} (in our case 630, 696, and 779 cm^{-1}). The intense bands around 500 cm^{-1} (in our case 460 and 512 cm^{-1}) are presumably caused by Me – O valence vibrations and the deformation vibrations of the silicon-oxygen tetrahedral ribbons. The presence of a doublet absorption band with maxima at 780 and 800 cm^{-1} is typical of quartz [4].

In heating the materials considered up to 1250°C no significant modifications are seen in the absorption spectra (Fig. 1). At a higher temperature, in connection with the formation of a melt, the structural groups disintegrate and the IR spectrum of glass has two absorption bands with maxima at 1100 and 460 cm^{-1}, which is the evidence of the substantial degree of polymerization of silicon-oxygen tetrahedra in ribbon-type silicates and a certain presence of skeleton silicates.

The analysis performed indicated that the waste of ferrous quartzite after dry and moist concentration is undoubtedly of certain interest as a component for the production of various silicate materials: wall ceramics, vitreous materials, and glass ceramics.

A subsequent experimental study established that the tails of dry and moist magnetic separation of iron ore introduced in an amount of 20% (here and elsewhere, wt.%) improve the technological characteristics of ceramics mixtures: decrease air and fire shrinkage and lower the drying and firing sensitivity of mixtures. At the same time they have a positive effect on the physicomechanical characteristics of fired samples.

It is possible to use the material considered in a quantity of 5 – 20% in mixtures for household majolica with water absorption of 16.5 – 20.0% and in densely sintered ceramic mixtures of low-temperature firing with water absorption below 5%. It is found that the material considered has a favorable effect on the properties of ceramic mixtures: lowers shrinkage, contributes to expanding the sintering interval of products, and has a simultaneous grog and fluxing effect.

The tails of dry and moist magnetic separation of iron ore introduced into mixtures in an amount of 8% were used to produce samples of ceramic tiles for interior wall decoration. The requirements on ceramic tile properties (water absorption, bending strength, TCLE) are met after a firing temperature of 1050°C.

The possibility of using non-fritted glaze coatings with high service and aesthetic parameters based on the materials studied is identified as well. Such glazes have good spreading capacity. Their color range includes greenish-brown, chocolate brown, dark brown, and other shades. The synthesized glazes do not contain dangerous components of classes 1 and 2 or volatile fluoride components, which contributes to improving labor conditions and the environment in industrial regions.

Furthermore, the waste of dry and moist magnetic separation can be used as a basis for the production of glass ceramics, i.e., rock ceramics and stone casting. The glass melts have a high propensity for crystallization, and the crystallization process for the formation of a glass ceramic structure can be intensely stimulated by chromium and iron oxides. Under thermal treatment a diopside-based solid pyroxene solution is formed, which imparts high wear resistance and chemical resistance to the end materials.

Thus, the possibility of controlling the phase formation process and the physicochemical and mechanical proprieties of glass ceramics is corroborated. The content of the product of iron ore concentration in the batch can constitute 85 – 90%, and the materials obtained can be recommended for making acid-resistant lining (rock ceramics and stone casting) or abrasive milling bodies (stone casting).

The use of the tails of dry and moist magnetic concentration of iron ore is obviously promising. The development of the Okolovskoe deposit would make a sizeable contribution to expanding the range of raw materials available in the Republic of Belarus and the product range of silicate articles for various purposes and also would make it possible to utilize waste generated in iron ore concentration.

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